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FLASHING LIGHTS AND BELLS AT GRADE CROSSINGS: PRESENT PROBLEMS AND DIRECTIONS FOR THE FUTURE

by

Ezra Hauer
Department of Civil Engineering
University of Toronto

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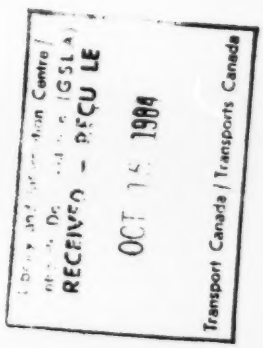

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17. Abstract

The purpose of this report was to diagnose what ails the flashing light type warning device for grade crossings, to survey possible remedies and to indicate profitable directions to pursue.

Recognized deficiencies of flashing light type protection are: poor conspicuity, sudden onset and inobservance by drivers. The conspicuity of flashers could be enhanced. It is not clear whether doing so is cost-effective. The remedy to the problem of "sudden onset" is an activated advance warning signal. The development of a proper device requires a cooperative effort between the highway authority and the railway. The Roads and Transportation Association of Canada may play in this a useful role. The poor credibility of flashers is a problem which can be alleviated by the use of constant-warning-time devices.

The use of traffic signals is one of many alternatives or improvements to flashing light protection that have been proposed. The report, concludes, however, that there is little to commend widespread use of traffic signals at grade crossings and recommends greater cooperation between railways, equipment manufacturers and government to solve the problem.

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17. Résumé

Ce rapport concerne les défauts du système de protection des passages à niveau par feux clignotants, le choix des mesures correctrices et l'orientation des travaux futurs.

Les trois défauts reconnus de ce type de protection sont: visibilité insuffisante du signal, soudaineté du signal et faible crédibilité entraînant un taux de désobéissance élevé de la part des automobilistes. Le premier est remédiable par une visibilité accrue, bien que l'on en connaisse pas encore le rapport coût-avantages. Le deuxième, par un signal avancé, dont l'étude serait le fruit d'un effort concerté des autorités concernées et des chemins de fer, avec la collaboration utile de l'Association des routes et transports du Canada. Quant au troisième, le correctif en serait l'emploi de signaux à durée constante, peu importe la vitesse du train approchant du passage à niveau.

Une des possibilités étudiées est l'utilisation de feux de circulation. Mais le rapport est arrivé à la conclusion que rien, ou peu de choses, justifierait une telle extension. Il recommande plutôt une meilleure coopération entre chemins de fer, fabricants et autorités concernées.

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ABSTRACT

The purpose of this report was to diagnose what ails the flashing light type warning device for use at railway grade crossings, to survey what possible remedies incline the mind and to indicate what appear to be profitable directions of thought and action to pursue.

We begin by tracing the technological history which gave us the present system and the ideological superstructure which evolved around it. The central role of liability, fail-safeness and safety is emphasized.

It is commonly believed that when flashers replace passive devices, accident occurrence is cut by 60%-70%. We think that this belief is incorrect. The real effectiveness may be much lower.

The most often recognized deficiencies of flashing light type warning devices are: poor conspicuity, sudden onset and inobservance by drivers due to large variations in warning times. The suggestion has been made that the use of ordinary traffic signals would be an improvement on all three scores. We conclude, however, that there is little to commend the widespread use of traffic signals at grade crossings and explain why.

The conspicuity of flashers has been improving over the years. It could be enhanced some more and even replacement of older and less conspicuous installations is possible. It is not clear whether doing so is cost-effective.

The driver finds himself suddenly facing flashing red lights if he is too close to the tracks when the signal comes on or if there is a too short sight distance on the approach to the crossing. The remedy to this is in the form of activated advance warning signals. The development of a proper device requires a cooperative effort between the highway authority and the railway. The Roads and Transportation Association of Canada may play in this development a useful role.

The poor credibility of flashers is a problem to which a cure has been available for some 20 years. The major Canadian railways are reluctant to use the medicine. It appears that one ought to take steps now in order to establish whether a change in attitude is warranted.

There has been no shortage of inventions, innovations, research and good ideas on how to make the archaic-looking flashing light type warning device better. There is little evidence of progress. Perhaps the missing ingredient is an agreement between the Government, the Railway Companies and the Equipment Manufacturers to cooperate in a Japanese-style attempt to bring novel technology to bear upon an old problem.

INTRODUCTION

Virtually all speeches, technical reports and learned discourses dealing with the protection of grade crossings begin by a standard litany of misery: so many killed, so many mauled... Surely the reason for conducting an inquiry is a hunch that we can do something about a problem, not simply its magnitude.

This inquiry has been set in motion by the hunch that it might be an idea to replace the flashing light signal at grade crossings by ordinary traffic signals such as are used at road intersections[1]. One is uneasy about examining a specific remedy without first determining the ailment. When the ailment is understood and described it may (and often will) turn out that there are many other remedies which deserve examination. In this particular case we deal with a technology (railway signalling) which exudes the respectability of old age. The temptation is therefore particularly strong to think that in the silicon chip age a better mousetrap can be built. The novice is perhaps unaware of the amount of research, development and frustration accumulated in this field. The conservatism in railway signalling is quite real but it is not due to inattention, lack of inventiveness or oversight.

Be it as it may, our purpose here is to diagnose what, if anything, ails the flashing light type warning device, to survey what possible remedies incline the mind, and to indicate what appear to be profitable directions to pursue.

A useful comprehension of the problem and a realistic assessment of what can be done about it requires a sympathetic understanding of how the system evolved. Accordingly, we begin by a review of the technological history and the related beliefs which together constitute the inertial mass of the issue at hand.

The natural next step would be to engage in a diagnosis: what (if anything) is wrong with flashing lights. This question is a legitimate one only if this warning

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1. The suggestion has been made within the context of thinking about the protection of grade crossings at which trains run as fast as 200 km/h (Canalog, 1978, p. 9, ref. 1). However, the idea is said to have merit for ordinary crossings as well.

device is useful in the first place. There is in the literature a perplexing contradiction. When crossbucks (passive protection[1]) are changed to flashing lights (active protection), many studies find a 60% - 70% reduction in accidents. Yet, when one computes (using so called "accident prediction formulas") the expected number of accidents for the two devices when used in identical conditions, the difference between them is often inconsequential. We feel, therefore, that it is worthwhile to at least state the paradox - this will be done in Chapter 2 - and only then to proceed to a diagnosis of deficiencies in flashing light type systems, in Chapter 3. Deficiencies of this nature need not be invented, only recognized. Both researchers and practitioners are outspoken in this respect. Our task will be to mould the diversity of comment into some clear pattern. Because deficiencies are oft discussed and man is inventive there is no shortage of proposed solutions. It so happens that the inventor and the professional with "railroad insight and experience" are often not the same person. As a result, progress is like a stunted tree with the twisted branches representing the many blind alleys. In Chapter 4 we will dwell on the merits of using ordinary traffic signals at grade crossings. In Chapter 5 we will review some of the major directions of recent technological innovation. Having diagnosed the problem and surveyed possible remedies, it remains to identify the course of research and action which appears to be promising, cost-effective, or in short - sensible. This will constitute the final chapter - Chapter 6.

1. Neither crossbucks nor flashing lights provide outright "protection". They merely aid the road user by "warning" him of the presence of the crossing and the imminent passage of a train. Thus, in general, the term "warning device" is a more precise description. However, the use of "protection" is so engrained in professional literature that we will use both terms interchangeably.

1. ON HOW WE GOT HERE AND WHERE IT IS THAT WE ARE

One often finds explications of standards and procedures given in technical terms. History tells another story. It gives clues to present practice which derives more from custom and continuity than from theory or design.

As soon as safety at rail-crossings became a problem (more than a century ago) a watchman with a red flag stopped traffic during the day. At night, he would swing a red lantern. A certain amount of nostalgia should therefore attach to today's flashing lights. They represent a red lantern swinging[1]. The rate of flashing is that which emulates a watchman, not that which provides the optimal stimulus for recognition. The shade of red used (until a few years ago) is not that which is best for light transmission and perception by drivers. The bell, so useful for horsecarts and buggies, cannot penetrate the soundproofed stereophonic vehicles.

The shade of red or the rate of flashing are items which curiously resisted change for the longest time. But now all new installations have broken with tradition and use more transparent shades of red[2] and faster flashing rates. All that had to be sacrificed in this case is some uniformity; older installations still conform to earlier standards.

However, there is another century-old event in the annals of the history of railroad technology, with much more profound and far reaching consequences. "August 20, 1887, marked one of the most important events in railway signalling, the invention of the closed track circuit..." (General Railway Signal, 1979, ref. 2). The idea is beautifully simple. The rails are divided into "blocks" by insulated joints and serve as conductors of electricity. The current passing through the rails holds a track relay in place. As soon as a train within the block "shorts" this circuit, there is nothing to hold the relay in place and it falls under the force of gravity. The fallen relay closes another circuit and thereby gives an appropriate indication that a train is within the insulated block. This simple concept forms the basis of block signal technology. It was first

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1. The "missing link" in the evolution from red lanterns to flashers is the "wig-wag" which was first used in 1910 and still retained the waving motion. It evolved into the flashing lights by 1920.
2. "The specifications for the red roundels has been revised. ...The newer roundels have been used in all new locations for the past three to four years." Letter to A.D. Cherwenuk from Mr. O'Hara, Secretary, RTC.

applied to wayside signals. In 1914 the same ability to automatically detect the presence of a train was first exploited to protect grade crossings.

A simple three track circuit system is shown in Figure 1. A train approaching, say, from the west is detected when its front enters the West Approach Section at B_1. This activates the flashing lights at the crossing. The signal goes blank again when the rear of the train clears the Island Section at R_2.

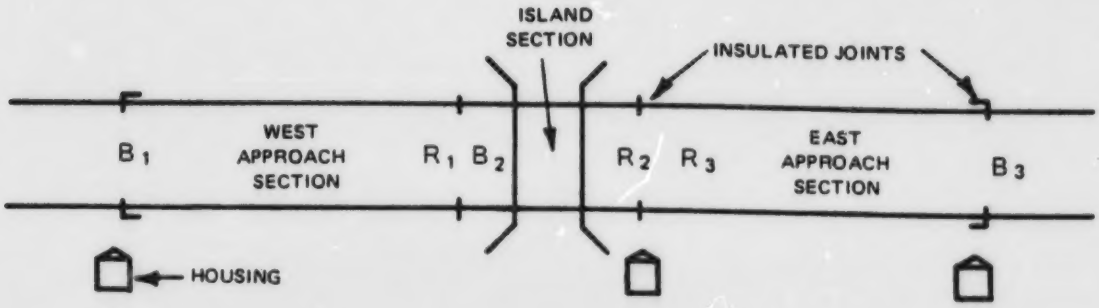

Figure 1 Three Track Circuit System
Source: Rail-Highway Grade Crossing Warning Systems Equipment & Application, Railway Progress Institute (p. 21)

The approach section must be long enough to ensure at least 20 seconds of warning time for the fastest train. Inevitably, all slower trains will take longer to reach the crossing. A train which stops on the approach section will keep the lights flashing until somebody stops them or until the battery runs out. The same will happen when someone puts a wire held by two stones across the rails, when the ballast gets so soaked that current can leak from one rail to the other and for a variety of other reasons.

The system is ingeniously simple. Because of its simplicity, it happens only very seldom that a train goes through a crossing and the lights are not flashing[1]. It is this attribute which earned it the adjective of being "fail-safe". Fail-safeness of this sort is much cherished by railroad signal engineers. It is the source of professional pride and intellectual fascination. In the course of time it seems to have become something akin to ideology or, in practical terms, a standard to which all design and

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1. The alleged "Mean Time Between Failure" is of the order of 10 years.

technology has to measure up before it is seriously considered for implementation.

The system is fail-safe in a specific, somewhat peculiar and narrow sense of the word. It is certainly not fail-safe in the sense that it prevents collisions between cars and trains or in that it prevents cars from running into each other or into ditches. To what extent the flashing lights protection is useful in reducing collisions will be discussed in more detail in Chapter 2. Here it is sufficient to say that it is not safe without fail in the sense that not all collisions are prevented. Neither is the system fail-safe in terms of warning motorists of the impending passage of the train only when the train is less than 20 seconds away. Warning times are often much longer. Failures of this nature are not entirely benign. They are believed to influence the motorists' risk-taking behaviour and thus to cause collisions.

Where the system is fail-safe is in almost never keeping dark signal condition when a train is less than 20 seconds away from the crossing. The commitment of the railroad to this particular brand of fail-safeness must have its root and origin in the aforementioned event of August 20, 1887. Its current and future repercussions are manifold. Two of these are so fundamental that they can be regarded as empirical laws of nature.

The first has to do with event detection - here the detection of a train. No real system for detection of events is perfect; it will miss the occurrence of some events (a "wrong-side failure") and will at times signify occurrence when no event took place (a "right-side failure" or false alarm). The two types of failures are usually linked. If you design or tune a system to provide very few wrong-side failures, you will often get many false alarms. You can reduce the number of false alarms on a system if you are willing to tolerate more wrong-side failures. The flashing light type grade crossing protection system aims to be near fail-safe in preventing wrong-side failures. This is why, in the words of G.J.S. Wilde (1975, ref. 3), it often "cries wolf".

The second empirical law of nature is about complexity and reliability. The more parts and components to a system, the more likely it is to fail. Because the basic track circuit is such a simple device, it is virtually certain that any technological innovation will be more complex and as such, less reliable. Having set the standard for wrong-side failure reliability by the simple track circuit, the introduction of more complex technology faces an almost insurmountable handicap.

It follows that a single-minded commitment to the high standard of the track circuit in guarding against wrong-side

failures will make it difficult to reduce the rate of false alarms and to introduce new technology aimed at improving the safety performance of the flashing light type protection. This observation seems to be borne out by past history.

There is a related issue which deserves attention and is best understood by contrasting traffic signals at intersections to flashing lights at rail crossings. On the face of it, the purpose is very similar. The traffic signal aspects convey three main messages. Green is understood to mean: it is your right of way; red: someone else has the right to proceed; a dark traffic signal is understood to mean: watch out - malfunction. In contrast, the rail crossing signal never says: it is your right of way. Road vehicles are at best uninvited guests on the crossing and enter at their own risk. At worst, of course, they are trespassing. By remaining dark and silent when no trains are about to cross, the railroad signal loses the ability to indicate malfunction. This may be partly an atavism - a trait inherited from the days of the swinging lantern which was either lit or absent. There may be technological reasons as well. Because wrong-side failures are not tolerated, each installation has standby battery power. The batteries are trickle-charged from the AC network and operate the flashing lights when network power fails. Provision of a continuous green or a flashing amber indication might require substantially more standby battery power[1]. A third reason may also be at work. Telling the motorist outright when he has the right of way carries with it obligations which are legal in nature. In addition to the technological and engineering care which the railroad exercises in ensuring that wrong-side failures do not occur, the railroad may not wish to be in a legally precarious position in the rare cases when such failures do occur.

The question of legal liability is of course one of the central issues. We will therefore return to it later in this section.

Because a dark railroad crossing signal does not mean malfunction and it is not acceptable that during network power failure the signals remain dark and silent, standby battery power has to be provided. At some point in the evolution of railroad crossing signals a "design decision" has been made matching lamp power consumption to practical battery size. Traffic signals require up to 150 watts of power; railroad crossing signals use 11 and 18 watt lamps

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1. This may be a superficial objection. When network power fails one could revert to present day operation - dark unless train is detected. Dark would then acquire the "malfunction" meaning.

with 25 watt lamps coming into use[1]. This dramatic disparity in power consumption is dictated by battery size. To offset the inferiority in total light emission, the optical system of the railroad crossing signal is quite sophisticated and focusses a rather narrow beam in the direction of the oncoming traffic. When properly aligned and focussed it is, in fact, superior to the ordinary traffic signal. As a result, careful aiming and frequent maintenance are needed.

The central role of the simple and reliable track circuit technology and the attendant frame of mind which requires fail-safe performance against wrong-side failures should now be evident.

It is not quite clear whether the single-minded pursuit of protection against wrong-side failures is in the best interest of safety. After all, it may encourage risk-taking by creating too many false alarms. It may be responsible for giving the motorist a low stimulus signal which he has difficulty in perceiving and due to its sudden onset, it may be creating unpredictable reactions and rear-end collisions. Perhaps in this case protection against legal liability is not identical with the interest of public safety.

We have found only one published paper touching on the subject of liability (Glater and Mond, 1979, ref. 4). It deals exclusively with the legal situation in the U.S. and as such has no direct relevance in Canada. However, insofar as the North American railroad industry has common institutions and professional organizations, it is unlikely that views and attitudes in Canada are very different from these prevailing in the U.S.

The authors begin from the premise that "...there has been a general reluctance to deploy grade crossing warning devices embodying new technology." (p. 1). They attribute this reluctance not to cost considerations but to the fact "that those responsible...believe that, should an accident occur, a railroad will be more likely to be held liable for the accident if it has employed new technology...rather than making no change at all." (p. 1). However, they found no case "in which a railroad was held liable...just because it employed grade crossing warning equipment embodying new technology" (p. 2). In reviewing the standards by which the law will assess whether a railroad acted reasonably, they find a spectrum of conditions. If no safer technology (than what has been used) is commercially available, "a user of current technology may not on that account be found negligent" (p. 7). At the other end of the spectrum, "once there occurs a general adoption of a particular new

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1. See Regulation 10 in Chapter 1183 of the National Transportaiton Act, Railway Act, General Order E-G.

technology...a railroad best protects itself from liability by deploying that technology" (p. 15).

It is unclear at this point whether the fact that "much of the equipment currently in use is based on designs developed in the 1920's and 1930's"(p. 1) should be attributed to the superiority of these designs or to a reluctance to use new technology. If the latter be the case, it is also not clear whether such reluctance is based on unsubstantiated folklore or on a deliberate strategy of avoiding liability by postponing the time at which a new technology begins to be generally adopted.

This concludes a brief review of the technological and ideological history which constitute much of the inertial mass of the issue at hand. Having cut open the Gordian knot we can now examine its entrails.

2. JUST HOW MANY ACCIDENTS DOES THE CONVERSION FROM CROSSBUCKS TO FLASHING LIGHTS SAVE?

The safety effect of going from passive warning by crossbucks to active warning by flashing lights can be investigated in two ways.

First, it is possible to compare the accident histories of crossings before and after conversion. Such studies are said to be of the "before and after" type. Second, one can compare the safety performance of crossings equipped by crossbucks to the safety performance of crossings equipped by flashing lights. Such studies are often called "cross-section" studies. Both approaches have their strong and weak points. Research reports on this subject are too many to be counted. Only a few "landmark" studies will be mentioned here.

In the "before and after" class two research efforts dominate. The first (California Public Utilities Commission, 1974, ref. 5) compared a ten year accident history before conversion to flashing lights to the accident history after conversion till August 1972. At 245 conversions from crossbuck protection a reduction of 64% in accidents was found (from 0.25 to 0.09 accidents per crossing per year).

Morrissey (1981, ref. 6) notes that the PUC estimates of effectiveness were "frequently criticized as being too high in view [of the fact that]...Flashing light crossings have an average accident rate which is 2.7 times greater than average of all crossings equipped with crossbucks".

This is, of course, unfair criticism because it is the heavier used crossings which get the more expensive protection. Still, to remove doubt, a new study based this time on U.S. national statistics has been commissioned.

Using four years of accident data (1975 to 1978) on 1165 conversions from passive control (stop signs, crossbucks, etc.) to active control (flashing lights, wigwags, traffic signals, etc.), Morrissey (1981, p. VIII, ref. 6) finds again an effectiveness of 65%. One year later, Coleman (1982, ref. 7) reports that earlier estimates have been revised and it now appears that conversion from passive protection to flashing lights reduces the number of accidents by 71%.

One might lay the matter to rest were it not that in cross-section studies, crossings which are similar in all respects except that one is protected by crossbucks and the other by flashers, seem to have similar accident histories. Thus, eg., Schultz et.al (1969, ref. 8) produces an equation (p. 18) which implies that flashers leave the hazard index unchanged.

Eight years later, Coleman and Stewart (1976, ref. 9) published findings of a study based on a much more extensive data set - 37,230 crossings. The data-set has been used to estimate parameters of equations to be used for the prediction of accident rates (number of accidents per year). We show here one of the four figures in their paper to illustrate the nature of the results. Thus, in Figure 2, at crossings with 10 trains per day and vehicle volumes up to about 140 vehicles per day, flashing lights are somewhat better. For higher vehicular volumes crossbucks have a smaller accident rate.

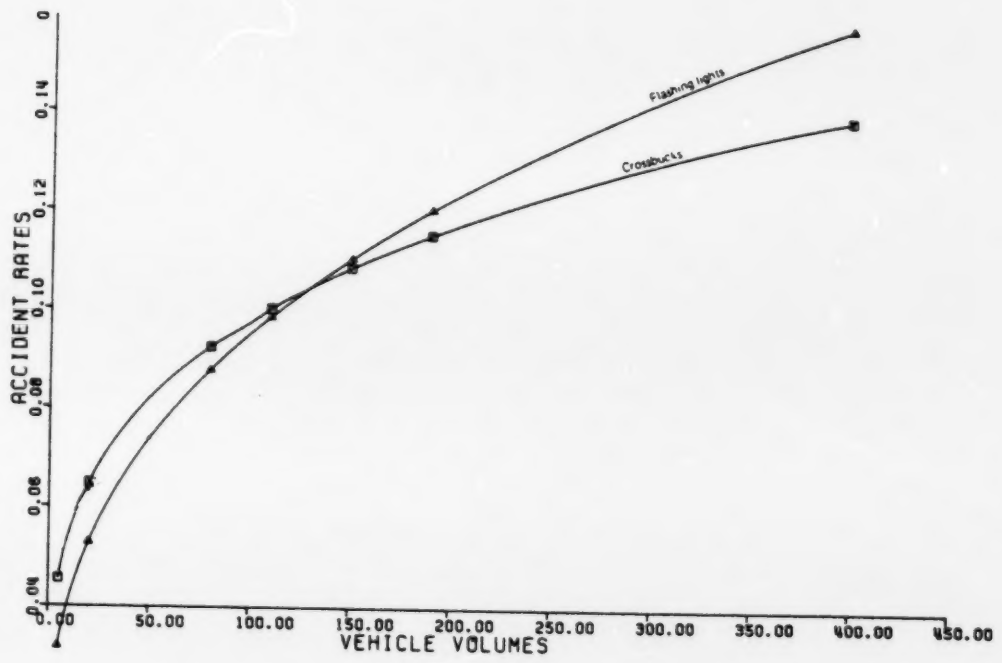

Figure 2 Single-track Crossings in Urban Areas (10 trains/day)
Source: Coleman and Stewart (1976, ref. 9)

The other three figures are similar in nature. Sometimes flashers are better than crossbucks (single-track - rural), sometimes the reverse is true (multiple-track - urban) and sometimes the two types of protection are equal in accident rate (multiple-track - urban).

A thoughtful and rigorous analysis of Canadian data has been performed by Zalinger etal. (1977, ref. 10) in the course of the Rail Safety Study carried out on behalf of the

Canadian Transport Commission. They find that in an urban area under identical conditions the number of accidents is not affected by going from lesser protection to flashers and in rural areas it is better to leave a crossing without flashers[1].

The most recent effort in this direction is the so called DOT Accident Prediction Formula" (Hitz, 1982, ref. 11). Using the "DOT Crossing Inventory [which] contains characteristics of all rail highway crossings in the United States" (p. 2) and sophisticated statistics, a rather complex formula has been proposed. Under typical and identical conditions, flashers seem to reduce the probability of accident occurrence by about 30%.

It appears that, while "before-and-after" comparisons indicate a 60% - 70% effectiveness, "with and without" cross-section analyses lead to entirely different conclusions.

One could be attracted by the similarity of effectiveness estimates derived from before-and-after comparisons and disregard the contrary results from cross-section studies. However, there is a hitch.

It is almost certain that estimates of protection effectiveness based on simple before and after comparisons are wrong. This is not a matter of pedantic hair-splitting. Because conversions from passive to active protection are partly motivated by the recorded accident history of that crossing, there is a built-in and systematic bias in such before-and-after comparisons which makes conversion look more effective than it really is. Without a reanalysis of the data it is impossible to say how large this bias is. It would not be surprising if one found that the real effectiveness is very substantially less than what it is purported to be on the basis of before-and-after studies.

Similarly, it is almost certain that estimates of protection effectiveness based on multivariate (regression-type) analysis, such as is common in cross-section studies, are also in danger of being wrong. To show why, consider the following table:

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1. The hazard index chosen by Zalinger et al is the number of accidents expected to occur at a crossing in a 5 year period. Using the coefficient in Table 3 (p. 264), in urban areas the use of flashing lights and bells instead of lesser protection increases the hazard index by 0.002 (0.072 - 0.070). At rural crossings, doing so increases the index by 0.039 (0.112 - 0.073). At crossings protected by flashers a typical hazard index will be in the 0.2 - 0.3 range.

Warning Device	Injury Data	Fatality Rate
Crossbucks	0.5129	0.1463
Flashing Lights	0.6402	0.2522

Source: Coleman and Stewart, 1974, p. 62 (ref. 12)

The higher accident severity associated with the use of flashing lights reflects, in part, the more difficult circumstances in which the costlier protection device tends to be used (faster trains, higher class roads which are also built for faster travel, proximity to schools, etc.). Therefore, the higher virulence of collisions is hardly surprising. It is, however, exceedingly difficult to account for all relevant variables which cause crossings to be different within the confines of a mathematical model. One can, therefore, not be certain that in a multivariate analysis all important factors have been taken into account. The results may reflect our inability to recognize or measure variables which are needed to properly capture reality.

It is unlikely that the paradox of obtaining a large estimate of effectiveness from before-and-after comparisons and a much smaller estimate of effectiveness from cross-section studies went unnoticed. Yet we found no mention of it except for the quoted hint in Morrissey (1981, ref. 6).

Curiously, even a peaceful coexistence of what is a plain contradiction has evolved. In the DOT Resource Allocation Procedure (Hitz, 1982, ref. 11), one first nominates crossings for improvement on the basis of the predicted number of accidents. This part of the procedure uses results of the cross-section - multivariate-regression analysis reviewed earlier. In the next stage one assumes flashers to be 65% effective. This estimate is based on Morrisey's before-and-after study. Surely, both cannot be simultaneously correct.

In summary, there is reason to believe that conversion from passive to active flashing light type protection is less than 65% effective in reducing the number of accidents. Just how effective it is, is difficult to say but it should not be too difficult to find out. Recently, analytical methods were devised to correct for "bias-by-selection" in before-and-after comparisons. These methods should be used on available data sets in an attempt to resolve the paradox. It stands to reason that marginal improvements to the current flashing light type protection must be considered within the context of its proven effectiveness. There is reason to doubt the prevailing concensus in this matter. We think that one ought not invest in new installations of the flashing lights type on the basis of the assumption that

they reduce accidents by 60% - 70% without first showing that this is indeed so.

Our mandate was to examine ways in which to make the flashing lights type protection better, not to examine its effectiveness. However, it did not seem quite right to proceed with such an examination without first pointing out that perhaps the effectiveness of flashers is overrated. Having done so, we return to the main subject.

3. DEFICIENCIES AND DEFECTS

In the introductory chapter we tried to trace the evolutionary history and technological constraints which fashion today's flashing light type grade crossing protection. This should lead to a somewhat sympathetic acceptance of the present-day device. Without this historical backdrop it is rather easy to recognize its many imperfections.

First, the signal is weak and too tightly focussed, at least in comparison to similar stimuli which the driver is used to. It is weak also relative to much of the competing "visual clutter". Second, it comes on suddenly, without prior warning. Often the motorist is put in a situation in which he must cross while the lights are flashing. He may panic, stall the vehicle or act unpredictably. Finally, there is the problem of credibility. The flashing signal does not convey much information. If you watched it start, it should tell you that a train will arrive in 20 seconds or later. Most people have no clue about the 20 seconds minimum. Their experience tells them that the time-to-train is variable, at times very long. If a train is long in coming and the driver decides to cross, he will believe that the train never arrived.

What is the factual basis on which these statements about alleged imperfections are made? The basis is perhaps twofold: firstly, the analysis of accident statistics in aggregate and the reconstruction of individual accidents; secondly, psychophysical laboratory-type research and the observation of driver behaviour at crossings. We will discuss briefly the content of this dual factual foundation of the alleged deficiencies: poor conspicuity, sudden onset and lack of credibility.

3.1 Poor Conspicuity

Possibly the best clues about the role of signal recognition in accident causation comes from a detailed accident reconstruction and event analysis at 43 flashing light type crossings by Knoblauch et al. (1982, ref. 13). Failure to recognize the signal (before it is too late) was found to be a major contributing factor to the subsequent collision with the train in 11 of 37 collisions. Thus in 26 of the 37 collisions, the driver did recognize the signal but for one reason or another chose to maintain his speed and enter the "non-recovery" zone. It must be noted that only vehicle-train collisions were analysed. This covers only about 20% - 35% of all crossing accidents (see Shoppert and Hoyt, 1968 Tables 15, 16, p. 20, ref. 14, and CANALOG, 1978, Table 2.23, p. 91, ref. 1).

A similar study in Canada (CANALOG, 1978, ref. 1) analysed files of 228 accidents occurring at crossings

protected with flashing lights and bells. The conclusions are similar to these reached by Knoblauch et al. (1982, ref. 13). In 21% of the cases the driver was "unable to stop" because he entered the non-recovery zone without recognizing the signals (Table 2.4, p. 56). The other major causes were "risk-taking" (50%), "stationary on crossing" (16%) and "misjudgement" (11%).

Presenting results in the form of percentages creates an impression of precision which may not be warranted. In this case, conclusions are based on relatively few accident investigations. Each such investigation requires a host of subjective judgements to be made. Neither the police officer nor the investigator employed by the railroad are making judgements which either entirely unbiased or very precise.

The following pattern emerges. Only 20% - 30% of all accidents on crossings are between the train and a vehicle. Of these, again only 20% - 30% have "failure to recognize the signal" as a major contributory factor. Taken together, this constitutes 4% - 9% of crossing accidents. In addition to collisions with the train, there are accidents to vehicles when the train is present (but not involved in the collision) and accidents to vehicles with no train present. These two accident types occur about equally frequently. When the train is present (and signals are assumed to be flashing) collisions are predominantly of the rear-end type (Shoppert and Hoyt, Table 18, p. 21, ref. 14). We have no clues about the role of signal conspicuity in this situation. Given free reign to speculation we guess that many of these might occur because the lead vehicle recognized the signal but reacted abruptly and unpredictably. A few accidents may also be due to late recognition at the signal by both the lead vehicle and the follower. In balance, it is not clear whether improved conspicuity would have any influence on this type of collision. Finally, signal conspicuity has no role to play in accidents when the train is not present. In summary, 20% - 30% of collisions with the train (the more severe accidents) or 4% - 9% of all crossing accidents are the target of measures aimed at improving signal conspicuity. Thus, if some improvement reduced the chance of nondetection by, say, 10% it would reduce collisions by 0.4% - 0.9%.

We found no information about the possible impact of improvements in conspicuity on the reduction of the chance of non-detection. The motivation for research into enhancement to conspicuity seems to rest on the following two premises. For one, insofar as the geneology of the present device can be traced to the swinging lantern, one should not be surprised if it was deficient in conspicuity. For two, we now know quite a bit about how visual stimulation depends on colour, contrast intensity, flash rate, size, placement and number of lights. Therefore, it is possible to suggest

more conspicuous devices. Because suggestions of this nature can be made, it is perhaps legitimate to regard the present device as deficient in conspicuity.

In the final account, the mere opportunity to reduce accidents is not a sufficient condition for action. One has to give thought to cost-effectiveness and acceptance. More on this in Chapter 5.

In discussing relevant research about visual stimulation we follow Ruden et al. (1977, ref. 15). First, there seems to be "ample evidence to demonstrate the superior conspicuity of flashing lights over steady lights" (p. 17). While the current flash rate is 35 - 55 per minute, Hopkins and Holmstrom (1975, ref. 16) suggest 120 flashes per minute as most desirable. In their views, short flash duration is the key to improved conspicuity. They recommend a duration of 0.1 second or less and espouse the use of strobe lights. Second, in terms of colour, red is bad at night but good during daytime. Orange was found to be good both in daytime and at night. The dark red (used presently on all older installations) reduces light transmission by as much as 90%. The third element relevant to stimulation is light intensity. Due to the low power consumption which is dictated by the need to ensure (at times) operation from standby batteries, present practice is to use a narrow beam. This makes aiming critical and difficult on approaches which are curved. Lens size is the fourth consideration. The trend in traffic signals has been towards 12" lenses to replace the traditional 8" size. "There is ample evidence that this change has been an improvement" (Ruden et al., 1977, p. 21, ref. 15). In Canada the 8 3/8" units are most common. In the U.S. 12" units are getting to be popular. Finally, the probability of detection is a function of placement and redundancy. There is evidence that placing flashers over the centre of the lane improves their conspicuity. Redundancy in the number of lights may exert influence mainly through reduced probability of obstruction.

3.2 Sudden Onset

"Crossings were found to have a turbulent effect on the traffic stream," and "...are believed to contribute significantly to multiple-vehicle accidents at crossings" (Shoppert and Hoyt, 1968, p. 2, ref. 14). Part of this turbulence may be due to the variability and unpredictability of driver response when suddenly faced with a flashing red signal and the prospect of being hit be a train. The onset of the flashing light signal is indeed sudden. It is raised from its normal, dormant and dark state without warning. A driver who at that instant is close to the crossing may do the unwise: slam on the brakes, stall, swerve and lose his nerve in other ways. We have found no reliable evidence to indicate that this is happenning. Drivers may be placed in a similar situation also in those

cases in which, due to road geometry, obstruction or signal misalignment, the flashing light becomes visible when it is too late to stop. Thus, there are two distinct cases of "sudden onset". In the first (driver-too-close-when-signal-comes-on), the subjective fear may be large because the driver may be indeed only a few seconds from the crossing. Objectively, however, there is no imminent danger of collision with the train because it is at least 20 seconds away. In the second case (signals-come-into-view-belatedly), sight distances are rarely so bad that the driver has only a few seconds to reach the crossings. But the train at that instant may be very close. Thus the objective danger is larger and its subjective perception perhaps smaller.

To delineate the magnitude of the problem is difficult. It is possible that a significant proportion of the "sta-tionary-on-crossing" collisions which constitute 16% of all collisions with trains are attributable to sudden onset of the signals and the subsequent panic reaction. However even a very detailed case-by-case accident analysis proved insufficent to trace such links (Taylor and Rebelo, 1980, ref. 17). In addition to accidents with vehicles stalled on the crossing, an unknown part of accidents with the "train present but not involved" may be associated with the sudden onset of signals.

Wilde, Cake and McCarthy (1975, ref. 3 and 1976, ref. 39) carried out detailed observations of driver behaviour at six crossings in Ontario. They argue "the first few seconds of the alarm period are functionally equivalent to an amber light phase," (p. 48). At traffic signals care is taken not to put the driver into a situation in which he can neither stop safely (being too close to the stop line to do so) nor cross before the onset of red. In contrast, the absence of something akin to "amber" at grade crossings will create for drivers too close to the crossing the necessity to cross against the red signal every time the flashers come on. This makes for decisional distress and may cause unpredictable driver action, which is perhaps undesirable. For one, the driver learns that he can get away with such behaviour. For two, the driver behind him is tempted to do the same. Here, we are touching on the issue of credibility to be discussed in the next subsection.

Compared to "poor conspicuity" and "lack of credibility" which are the most often identified weak spots, the issue of "sudden onset" has taken the back seat. There is little direct evidence in accident records to warrant pointing an accusing finger. On-site observation is difficult because, for each signal activation there may or may not be a vehicle near the crossing and signal activations themselves are not too frequent. Thus, Wilde et al. (1975, ref. 3), in recommending remedies, have to rely more on a general sensitivity to "human factor" issues than on analysis of "critical incidents" (Appendix D, 125-132). In the

same spirit the recent design, development and testing of activated-advance-warning-devices (Ruden et al, 1982, ref. 18) does not seem to rely on some sort of explicit accounting of potential benefits or a cost-effectiveness analysis[1].

3.3 Lack of Credibility

Providing for people is a frustrating business. You tell them that a train may be crossing soon, they perceive the message and proceed onto the tracks, often around lowered gates. Surely a person licensed to drive knows the consequenses of being hit by a train. Yet, he is willing to take the risk. There is something bordering on incomprehensible in this behaviour. It is also discouraging. Save for complete grade separation, how can one hope to forestall such accidents?

All this may be true. But there is another side to the coin. The sign of a sane person is that he learns from experience, trusts his senses and makes decisions on the basis of both. If by his experience the message (flashing lights) is not credible and the train is nowhere in sight, it may seem useless and demeaning to sit and watch the monotonous dance of the flashing lights. Even obedience of the law has its limits.

These are the opposite faces of the coin. We will examine the substance of which it is made.

The clues embedded in accident reconstruction will be examined first. Knoblauch et al. (1982, ref. 13) found that in 26 out of 37 vehicle-train collisions examined, the driver recognized the signal in time to stop safely yet still decided to proceed. In 17 of these 26 cases the driver not only recognized the warning signal but also did see the approaching train[2]!

The much larger Canadian data set leads to much the same conclusions. Out of a total of 228 vehicle-train collisions at crossings protected by flashers and bells, 113 are attributed to the "driver [who] may see the train, recognize that there is very little time to cross before it arrives, but chooses to take the risk by trying to beat it in a race to the crossings" (CANALOG, 1978, p. 45, ref. 1). In addition, 24 cases involved "misjudgement". The circumstances are much the same. The risk-taker plays "chicken" with the train. The misjudging driver errs in judging

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1. J. Coleman relates (private communication) that cost-effectiveness will be addressed in a follow-up study.
2. These findings are based on the examination of accident reports and on-site visits.

distance and speed. The distinction between "risk-taking" and "misjudgement" is perhaps one of attitude.

If these findings are true, one is led to conclude that in 46% - 50% (17/37 and 113/228) of vehicle-train collisions, neither the lack of signal conspicuity nor the lack of signal credibility play a role. Drivers see the signal and see the train coming yet decide to cross.

This finding is difficult to accept and therefore one is inclined to grasp at alternative explanations.

Is it possible that these drivers have to wait at the signal for a long time and take risks while blinded by frustration? Of the 26 drivers (Knoblauch, 1982, ref. 13) who recognized the signal only 5 actually stopped in front of the crossing. The remaining 21 maintained their speed into the "non-recovery" zone. Thus, inordinately long waiting time does not appear to explain risk-taking. Even so, Berg (1982, ref. 19) using the very same data states that the "predominant pattern of contributing factors to these accidents involved extended signal warning time (in excess of 30 seconds)" (p. 24-F).

Is it possible that the files on which these findings are based are somehow unrepresentative or unreliable? Surely the after-the-fact statement about whether the driver perceived a signal or did see the train coming must contain an element of uncertainty. The CANALOG findings are based on investigations conducted by the General Claims Departments of the railways. "These departments are charged with investigating the details of each accident sufficiently to arrive at a legal definition of the course of events and of responsibility..." (CANALOG, 1978, p. 48, ref. 1). Due to the "legal" and "responsibility" emphasis it is possible that risk-taking by the driver naturally gets to be the centre of attention and this is later reflected in statistical tabulations. Knoblauch's information about the sequence of events leading up to the collision is based (in the main) on North Carolina and Wisconsin State accident reports. One will never be certain about what the driver did or did not recognize. However, there is no reason to think that the results are biased in one way or another.

With due reservations and qualifications, these two investigations lead one to conclude that in about 1/2 of all vehicle-train collisions, the driver could see the approaching train and therefore, in these cases, "signal credibility" is not the issue. If 50% of the vehicle-train collisions are mainly due to such "risk-taking" and 20 - 30% are mainly due to failures to recognize the warning signal, this leaves 20% - 30% of such accidents in which credibility may play some role. Note again that vehicle-train collisions are only about 1/3 of all vehicular accidents at such crossings.

The issue of credibility arises again and again in the literature as one of the major deficiencies of the active railroad signals. The fear is that the experience of false alarms and long waiting times induce drivers to disregard flashing lights. Once they do so, or see others getting away with it, the inclination is further reinforced and the warning signal sinks even lower in terms of the respect it commands. Eventually, they do so once too often. Berg (1982, p. 24-F, ref. 19) concludes that the "frequently observed pattern of motorists crossing railroad tracks while flashers are operating is believed to be due in large part to extended warning times. ...it was found that the warning times for the accident-involved trains averaged about 70 seconds and ranged up to almost 9 minutes."

It is difficult to form a comprehensive picture of how variable warning times in fact are and thus what "experience shaping" role they play. Sanders (1973, ref. 20) shows a graph of warning times measured at six active crossings. It serves to point out the fact that while for the 4 fast trains observed (>50 mph) the warning time was about 30 seconds, for the 30 or so slower trains recorded (<50 mph) the warning times averaged 60 seconds. One train took nearly 12 minutes to arrive, eight times signals were activated for no apparent reason.

The variability observed by Sanders is, so to speak, built into the system. In the words of Matthews (1982, ref. 21) "Many of our present day active warning systems were installed many years ago when high speed passenger trains were prevalent. Now, some of these lines are used only by slow or moderate speed freight trains. In order to have a twenty-second warning time for a train travelling 80 mph, it is necessary to have the approach tracks' circuits extend approximately 2400 feet from the crossing. A train travelling 25 mph would then activate the warning equipment at this crossing over a minute before the train arrives at the crossing."

Wilde et al. (1975, ref. 3) provide the following data:

Warning Times (seconds) at Six Crossings

	Crossing Number					
	1	2	3	4	5	6
Minimum	50	30	30		19	17
Maximum	205	67	67		137	116
Mean	74	43	42	30	59	46
Standard Deviation	53	21	13		42	23
No. of Trains	8	3	9	1	6	17

It is perhaps such variability which leads Hopkins and White (1977, p. 7, ref. 22) to state:

> "At grade crossings...experience may often have led to an expectation that either no train is coming or that there is at least likely to be a quite sufficient time for a safe and leisurely crossing. There is also the possibility of a wait of several minutes while the train passes. ...the motorist may well perceive the message of the warning to be ambiguous or possibly fraudulent, with a significang penalty [if he decides to wait and] with no corresponding benefit if one "plays safe"."

In coming to grips with the question, "Why is there a credibility problem", Coleman (1980, ref. 23) lists: variation in warning time, equipment malfunction, expectations about train schedules, and radio news bulletins of the type: "crossing is malfunctioning AGAIN".

Here is how matters stand. It appears that some 70% of all vehicle-train collisions occur after the motorist has perceived the warning provided by flashers and decided to disregard it. Some 16% of drivers are alleged to ignore the flashers and bell warning[1]. To what extent this behaviour is due to the variability in warning time is difficult to say. What experts know about human behaviour in general, makes it a plausible conjecture.

Would drivers still approach the crossing and make up their mind based on whether they hear or see the train even if the warning time was constant? The clues from accident investigation and reconstruction indicate that such behaviour is not uncommon. If the variability in warning time is the culprit, countermeasures of one kind are indicated; if inability to judge distance or speed, risk-taking or suicidal motives dominate, quite a different set of measures should be contemplated.

The idea to use traffic signals at grade crossings (CANALOG 1978, p. 9, ref. 1) probably has its principal roots in the credibility problem. The argument goes as follows: since so many accidents are due to drivers who ignore the message conveyed by flashing lights, let us look for a traffic control device which the drivers are accustomed to obeying - a common traffic signal.

Because of the importance of the idea in motivating this work it is best to address the issue in a separate chapter.

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1. Policy Position Paper - Operation Lifesaver

4. TRAFFIC SIGNALS - PROS AND CONS

A brief review of past research and recent developments might help set the stage.

Wilde et al. (1975. ref. 3) contemplate the possibility of "replacing the present system by a `traffic light' type arrangement" (p. 48) in order to reduce the difficulty of the decision (to stop or to cross) which the driver has to face when the signal comes on. Such a `traffic light' would also reduce the number of instances in which it is impossible to stop safely and therefore the driver proceeds to cross against the flashing red. The authors, however, reject the idea and "believe...that it would do little to alter the present patterns of behaviour or accident rates" (p. 49).

Two years later, Hopkins and White (1977, ref. 22) also took a relatively negative position towards the use of traffic signals at grade crossings. Their main argument is contained in the following passage:

> "The use of conventional highway traffic signals at grade crossings has long been discussed ...The basic argument in favor of such devices is that they generally receive a high level of obedience at highway intersections. However, it is not clear whether this would be transferred to the grade crossing application; mixed results have been found in the analogous use of `Stop' signs. ...The crucial question...appears to be credibility. [In this respect]...traffic signals appear unlikely to offer...marked improvement. One has only to consider the behaviour of motorists at a malfunctioning highway traffic signal...After a certain point, traffic begins to move through the red signal." (p. 81, 82).

In spite of such pessimistic views the idea of using (Optically Programmed) traffic signals has been examined in more detail by Peterson and Boyer (1977, ref. 24) and selected from among several innovative concepts as worthy of further consideration. The emphasis there is on the technological issues. The improvements hoped for are better visibility and the possibility to show amber to the driver who is too close to the crossing to stop safely and simultaneously to show red to the driver who is further upstream. Problems of driver behaviour, credibility, jurisdiction, liability, acceptability by the railways, etc. were not discussed.

The CANALOG (1978, ref. 1) study comes next. In searching for ways to protect grade crossings used by high speed trains the conclusion is reached that: "...further

improvement[1] might be expected if standard traffic lights were provided to control traffic approaching the crossing instead of the present flashing lights and bells." (p. 9). The main argument seems to be contained in the passage:

> "The most effective countermeasure to reduce the speed of drivers unable-to-stop, is to introduce regulatory as opposed to warning signs to control speed of vehicles, since drivers respect these signs standard traffic lights are bound to be a good alternative, as they create a familiar condition as well as a universal regulatory standard" (p. 234).

Also, since the use of signals is contemplated in conjunction with barriers, the "traffic signals would protect crossing barriers and any driver hitting the barrier would be known to have broken the law by overrunning a red traffic light." (p. 277).

A systematic research program which considers the use of ordinary traffic signals at grade crossings has commenced at the University of Tennessee in 1980. The objective is "to develop innovative active warning devices" (Hungerford and Heathington, 1981, ref. 25). Some 30 experts from railroad companies, signal manufacturers, consultants, universities and governments were asked to help in generating new and practical concepts and in rank-ordering them. Of the 8 innovative concepts so devised, the intention was to take the most promising 5 for testing in the laboratory and of these, the three best were to be field tested. We are now at the point in time at which the laboratory work has been concluded. (Heathington, Fambro and Rochelle, 1984, ref. 26).

The results of the ranking are shown in Figure 3:

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1. In addition to the use of double frangible barriers as far from the crossing as practicable.

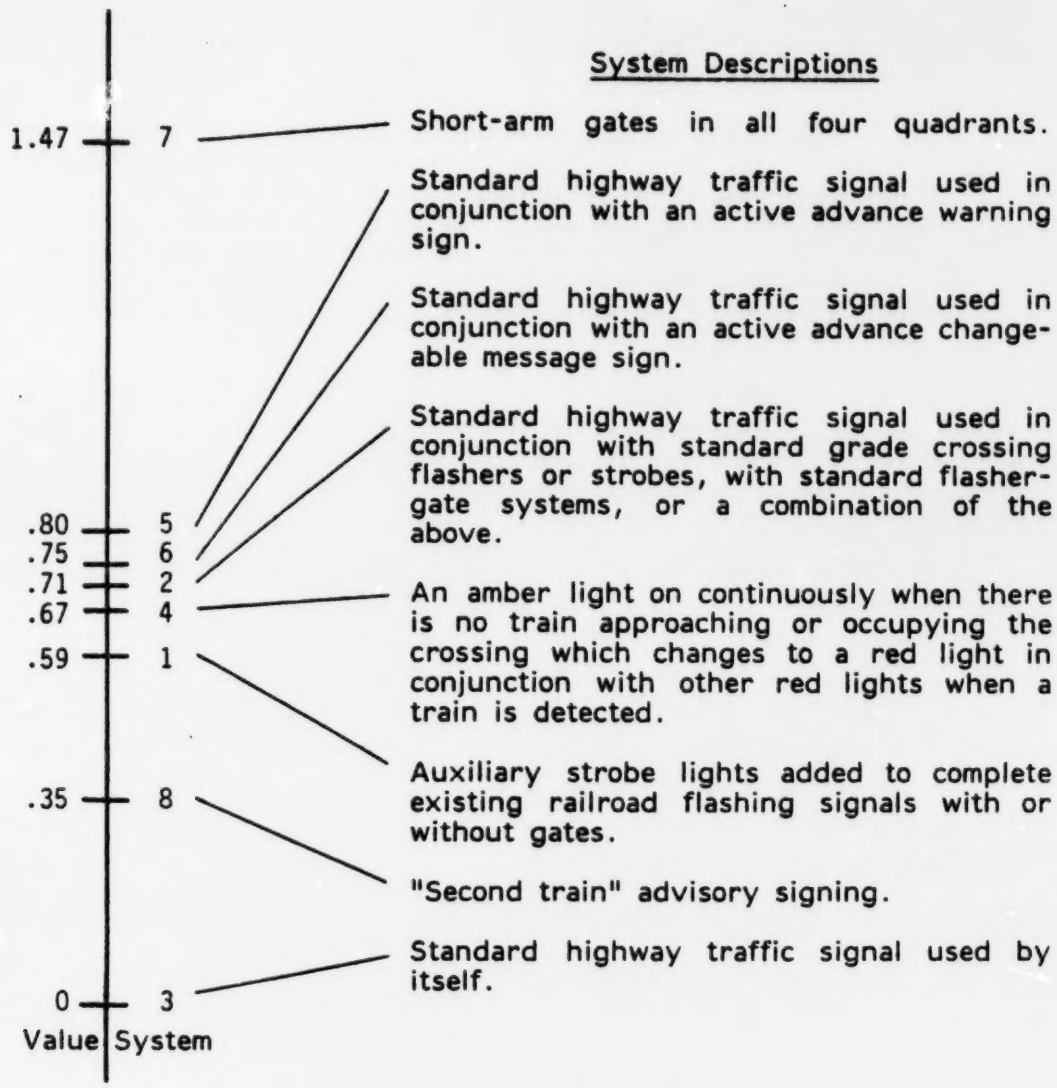
System Descriptions
1.47
7
Short-arm gates in all four quadrants.
Standard highway traffic signal used in conjunction with an active advance warning sign.
Standard highway traffic signal used in conjunction with an active advance changeable message sign.
Standard highway traffic signal used in conjunction with standard grade crossing flashers or strobes, with standard flasher-gate systems, or a combination of the above.
.80
5
.75
6
.71
2
.67
4
An amber light on continuously when there is no train approaching or occupying the crossing which changes to a red light in conjunction with other red lights when a train is detected.
.59
1
Auxiliary strobe lights added to complete existing railroad flashing signals with or without gates.
.35
8
"Second train" advisory signing.
Standard highway traffic signal used by itself.
0
3
Value
System

FIGURE 3.

RESULTS FROM THE ANALYSIS OF PAIRED COMPARISONS OF THE SYSTEM ALTERNATIVES

Source: Hungerford and Heathington (1981, ref. 25), Figure 10

The panel thought the use of the standard highway traffic signal by itself to be equivalent to use of the current flashers and bells protection. It is only the addition of some advance warning component which renders the traffic signal concept interesting. Accordingly, the "concept of the standard highway traffic signal used by itself ...has been completely eliminated from further

consideration." (Hungerford and Heathington, 1984, pp 40, 41, ref. 25).

At this point some rethinking must have taken place. Six (instead of five) systems were tested under laboratory conditions by 32 test drivers in instrumented vehicles driving repeatedly around a course with devices actuated at random. Somewhat surprisingly, the two highway traffic signal systems tested did not have an active advance changeable message sign nor standard flashers. They were, however, supplemented by a one-bar or three-bar white strobe light and a "signals ahead" sign.

It is not too clear how the results of the test are to be interpreted. Heathington et al find, for example, that drivers react somewhat faster to flashers than to highway traffic signals. We are unsure that this is good for safety.

Maximum deceleration rates have also been measured. When caught close to the crossing drivers reacted much in the same way - irrespective of the device which conveyed the warning. When caught further away, there are perhaps differences but no clear pattern. The authors recommend that 3 of the 6 devices be field tested.

This concludes the review of what published material speaking directly about traffic signals at grade crossing came to our attention. It remains to address the several principal issues which now emerge and to form some opinion.

a. Will the use of traffic signals at grade crossings make for fewer violations and less risk-taking?

Circumstantial evidence from observance of stop signs is relevant. Sanders et al. (1978, ref. 27) find that:

- stop sign observance at railroad grade crossings is less than at nearby highway intersections.
- compliance with stop signs increases with train volume.
- obedience of stop signs at highway intersections is not adversely affected by disobedience of stop signs at grade crossings.

Thus, if behaviour at stop signs is similar to behaviour at signals, one should not hope to gain much from a "transfer of respect". On the other hand, perhaps one does not need to worry about the adverse effect at road intersections of using traffic signals at grade crossings.

Traffic engineers do worry about the deterioration in observance which comes with proliferation and needless use. Some of this worry may be well founded. Consider, for example, that what appears to be a decline in the observance

of the stop sign seems to develop as its use and misuse became widespread.

Summary of Previous Research
on Driver Behavior at STOP Signs

Category	Morrison (1931)	Fisher (1935)	Eliot (1935)	Hanson (1960)	Leisch (1963)	Beaubien (1976)	Dyar (1977)
Full Stops	47%	45%	38%	20%	17%	22%	12%
Rolling Stop	42%	34%	42%	69%	69%	48%	60%
No Stop	11%	21%	20%	11%	14%	30%	28%

Source: Stockton, Brackett and Mounce,
Stop Sign, Yield and No Control at Intersections.
U.S. DOT, FHWA/RD - 81/084, Washington D.C., 1981

It may not be legitimate to arrange diverse studies in chronological order and from this sequence to come to conclusions about the existence of a time trend. Nevertheless, there is a strong belief among traffic engineers that use of control devices where not warranted adversely affects their observance in general. We found no solid evidence to substantiate this belief. However, it would be unwise to disregard it. In any case, the aforementioned study by Sanders et al (1978, ref. 27) is too small to conclude that a "transfer of disrespect" does not exist.

A related issue deserves airing. If traffic signals will be used at grade crossings without simultaneous action to reduce the variability of warning time, they will be frequently disobeyed. Irrespective of whether there is a "transfer of disrespect" from crossings to intersections, the mere fact that by putting signals at crossings we would increase the prevalence of law breaking must be considered with gravity.

We return now to the question originally posed. The use of traffic signals has no bearing on the variability in warning time. Therefore it has no effect on the causes of either risk-taking or actions due to impatience. Its only effect in this respect is to make crossing against red illegal. Since enforcement of this law at crossings would be impractical, we conclude that the use of traffic signals at grade crossings is unlikely to make much of a dent on the number of drivers who cross against red. Nor is it likely to carry over and adversely affect driver behaviour at intersections. What it would accomplish is to increase the number of instances in which the Highway Traffic Act is violated.

b. Will the use of traffic signals at grade crossings reduce the amount of "turbulence" at crossings?

There does not seem to be much extensive empirical evidence on which to base an opinion. Wimber (1982, ref. 28) examined the differences in speed, deceleration and jerk when drivers approach an ordinary flashing light type signal and when they approach a similar signal which flashes amber for 5 seconds before flashing red. Due to the limited number of observations, no significant quantitative differences were found. Qualitatively, the flashing amber was said to be associated with more stable and purposeful braking.

On this score, one is led to conclude that the provision of an amber phase before the onset of red would act mainly to reduce the number of drivers who are forced to go through red because they are caught too close to the crossing. This is beneficial in its own right but has no direct safety payoff. It might also aid in reducing some unpredictable reactions and reduce turbulence. It is, however, fairly clear, that instead of displaying flashing amber at the crossing (as part of a modified railway signal or as part of a traffic signal) one can help the driver better, by warning him in advance of the crossing that when he gets there he will find the red lights flashing. (See, eg, Wilde 1975, pp. 49-58, ref. 3).

c. Will the use of traffic signals at grade crossings provide a better stimulus for detection by drivers and thus help to prevent some of the "unable-to-stop" accidents?

Insofar as traffic signals emit more light, do not have to be so carefully aimed and drivers are perhaps more accustomed to them or more motivated to recognize them, the answer is yes. However, the question is improperly posed. The inferiority of the flashing lights derives from the requirement that they be able to operate for 1-7 days using only standby (battery) power. It is impractical to operate traffic signals from batteries. Therefore, if traffic signals are to be used at crossings, a fall-back low power consumption light unit - similar to the flashers - would have to be retained. If so, the real question is: What light source should be used in addition to flashers while network power is available?

Some of the options are:

i) ordinary traffic signal;
ii) flashing red when activated (60w - 150w), otherwise dark;
iii) flashing amber when activated followed by flashing red (60w - 150w), dark otherwise;
iv) flashing red when activated, otherwise flashing amber (60w - 150w)

From the "conspicuity" or "stimulus" point of view there does not seem to be a clear advantage to the first option (traffic signals) over the other three. The possible advantage of "familiarity" which the traffic signal has is

balanced by the superiority of "flashing" which characterizes the other three options. Options ii) and iii) are a less radical departure from present practice and philosophy in that they retain the dark aspect when not activated and are therefore, perhaps more acceptable.

We are now in a position to summarize the diverse strands of argument.

- There is no evidence that much of the authority which the traffic signal has when placed at road intersections can be carried over to the grade crossing unless one simultaneously ensures that the variability in warning time is reduced. It bears restating that problems of warning time variability stem from imperfections of train movement detection and therefore traffic signals would convey just as poorly credible messages as flashers and bells do.

- A traffic signal is better than a flasher in that its amber phase can be used to reduce the number of occasions on which drivers must go through red. It might also help to reduce accidents in which drivers panic at the onset of red, run off the road or stall on the tracks. However, a driver can be helped better if the "amber phase" is placed upstream of the crossing in the form of an activated advance warning.

- A traffic signal placed overhead using 60w - 150w bulbs is likely to be more conspicuous than the current flashers using 18w - 25w bulbs placed to the side. However, it does not seem at this time practical to operate traffic signals using standby battery power. When network power is used, flashing signal arrangements are more attractive than the solid indications of the traffic signal.

So far, we focussed on the potential advantages of using traffic signals at grade crossings. It remains to review briefly the arguments against their use; we can think of two.

- First, it appears very unlikely that a system which is not operational when network power fails has a chance of being acceptable. If so, the traffic signals will have to come in addition to the regular flashers. The potential advantages to be derived from this additional expenditure appear to be slight.

- Second, telling the driver (by displaying green) that he has the right of way on the crossing would be a radical departure from current railroad practice and philosophy. Its ramifications are manifold. Some are legal - who has jurisdiction over what and who is liable for what; some are technical - how does one ensure that the traffic signal aspect and the railroad signal aspect always agree; some are administrative - how do the highway and railroad authorities share costs and coordinate duties.

When analysed in this manner, the idea of using traffic signals at grade crossings does not seem to be attractive. However, it is possible that the whole is more than the sum of its parts. After all, the use of a beefed-up traffic signal has been recommended for testing by the experts assembled at the University of Tennessee. It is difficult to believe that they would put together a concept which is not worthwhile exploring. Perhaps in this case it is best to wait for the fruition of the results of their work.

5. DIRECTIONS, IDEAS AND INNOVATIONS

Some of the basic forces which strain the system have been alluded to in the Introduction: the technology which changes slowly, the belief in a better but undiscovered silicon chip mousetrap, the straightjacket of fail-safeness and the veiled gorgon of liability which causes instant petrification to innovation. In Chapter 3 we focussed on specific defects and deficiencies in a more systematic manner. Having discussed the merits of the traffic signal idea in the last chapter, we will now attempt an orderly (if not exhaustive) review of improvements and innovations considered in the past and being worked on at present.

Poor conspicuity, sudden onset and lack of credibility were noted in Chapter 3 as the main problems which plague the flashing light type protection of grade crossings. We will discuss improvements and innovations aimed at rectifying these three problems in the same order. The remaining technological innovations will be discussed under the heading "Additional Good Ideas".

5.1 Ways to Improve Conspicuity

In Chapter 3 we noted that the belief in the possibility of enhancing safety by improving conspicuity rests mainly on two premises: a) the origin of the present device is the swinging lantern of old and the suspicion that improvements are therefore possible; b) the expectation that armed with modern understanding of visual stimulation one will identify the required modifications.

We pick up the historical thread in the mid-seventies. Hopkins and Holmstrom (1976, ref. 16) review recent advances which contributed to better conspicuity. They note that current specifications are a modification of existing technology and practice. Working entirely within the code allows only for gradual improvement, not radical departure. Based on requirements of warning light intensity, flash rate and duration, they conclude that xenon strobe lights offer promise. Installation proved easy and costs moderate. The authors thought that better signal conspicuity has been attained and the need for careful alignment and maintenance has been eliminated (see also Hopkins, 1977, ref. 29 and Hopkins and White, 1977, ref.22).

Concurrently, Ruden et al (1977, ref. 15) published a description of the results of their efforts. Starting more or less from the fundamentals of perception, they designed and tested two devices. Amongst the conclusions, they note that white xenon strobe lights as an add-on to standard flashers improve conspicuity both in the laboratory and in the field. However, they end with the sceptical observation that "there appears to be no uniform solution to increasing the

conspicuity of active grade crossing warning systems...What such an installation will do to accident rate reduction is an unanswered question..." (p. 13)

One year later there is reference to research about red strobe lights as add-ons to flashers and their use also on locomotives (FHWA, 1978 p. 235, ref. 30). Later, Coleman (1982, ref. 7) mentions several alternative ways to increase signal visibility which are being investigated (use of increased commercial power, use of sealed beam light units, dual filament bulbs, aids to the maintenance of signal alignment).

The work begun at the University of Tennessee in 1980 culminated in the laboratory testing of six active warning devices, of which three were equipped with various configurations of white bar-strobes. Flashers with an overhead red strobe light proved better than flashers without strobes; highway traffic signals with a white bar-strobe in each lens were more effective than ones with a white bar-strobe in the overhead red signal lens only (Heathington et al., 1984). Two indications of implementation came to our attention. Heathington et al. (1981, p. 18, ref. 26) mention the system developed by Stepp in cooperation with the Chessie system. Hopkins (1976, ref. 16) mentions that the Union Pacific Railroad carried out a test program and installed xenon lights in a variety of forms at grade crossings in 12 states. It is not clear whether in either case the effect on the motorist has been explored.

Incomplete as this brief review may be, several features of recent history appear with clarity. First, gradual improvements do take place (lighter red, better optical systems, etc.). Second, the use of strobe light seems to have gone in the direction of supplementing, rather than replacing, the standard flashers. Third, it remains unclear to what extent improvements in conspicuity have contributed to safety or can do so. In consequence, it is impossible to form a defensible view on the merits of investing in conspicuity enhancement.

Since the conspicuity of commercially available flashers has been improving, new installations are more conspicuous than older ones. Should there be a program of retrofitting? This is a question of cost and of effectiveness in improving safety. As noted earlier, little is known about the relationship between better conspicuity and safety. As a result, there is no way to judge the merit of retrofitting (or for that matter of paying more for more conspicuous flashers). It follows that, before anything else, one has to come to a defensible view on the reduction in accidents obtainable by better signal conspicuity.

The same cost-effectiveness question holds when the addition of xenon strobe lights is contemplated. There is,

however, an additional unanswered question. The original intent was to replace the incandescent flashers by xenon strobes. It is not clear from the published literature why only add-on applications are now being considered[1]. This shift fundamentally alters the situation. In the former, one would expect a gradual introduction of a more conspicuous device (xenon strobe lights) which is similar in cost to flashers. In the latter, the added cost of xenon lights might have to be justified by special circumstances at specific crossings.

Is it that a superior technology has fallen victim to the power of standards which, of necessity, reflect an existing (and possibly inferior) technology? The question deserves an answer. Since all of this research and development has occurred in the U.S., perhaps it is best to wait and see what comes of it in the end.

5.2 Activated Advance Warning

Wilde et al (1975, ref. 3) suggested to use activated advance warning signals so that drivers be spared the sudden onset of red flashers when they are too close to the crossing. By placing a "lead warning signal" some distance upstream of the crossing and activating it a few seconds in advance of the crossing signal, no driver would be caught "too close", drivers would not slow down unnecessarily and, on the whole, traffic stream regularity and safety would be served. Seven years later, Ruden et al. (1982, ref. 18) published results of research on the design, development and testing of several "activated advance warning devices". One of the devices is recommended for deployment and guidelines are given for its operation.

Reading between the lines, Wilde et al. argue that the absence of advance warning capability is a general deficiency of flashers (and gates) and accordingly suggest a remedy with general applicability. In contrast, Ruden et al. (1982, ref. 18) define the specific and limited circumstances in which activated warning should be used: crossings with "sight distance" problems; crossings on downgrades where it is difficult to stop, etc. They do not share Wilde's conviction that even when such local problems do not exist, the sudden onset of red is a source of difficulty. Accordingly, their device is for problem locations, not for system-wide application.

To put the issue into sharper focus, remember that from the instant the signal is first visible, some 10-15 seconds

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1. Private communication indicates that the reluctance to replace incandescent lights by strobes is linked to the fear of liability.

are needed to stop in a comfortable and controlled manner from 80 km/h. At those "problem" sites at which, due to alignment and visibility problems, drivers do not have that much time, Ruden et al. recommend that activated advanced warning signals be considered. Wilde et al. might argue that there is a good chance[1] that when the red light begins flashing there is a car within 10-15 seconds of any crossing. Its driver is not given sufficient time for a controlled stop. Thus, while at a few "problem" crossings, all drivers arriving while the flashers are on face a difficult task, some drivers[2] face the same difficulty at all crossings.

Clear technical solutions are not easy to devise. Thus, for example, Ruden et al. (1982, ref. 18) recommend the use of 110V AC power to ensure proper daytime visibility. They also find that the message "TRAIN WHEN FLASHING" is best (p. 8). Immediately the spectre of liability raises its ugly head. During a power failure the sign would imply that there is no train and a driver facing the flashing red at the crossing would be doubly surprised. Therefore, Ruden et al opt for the watered down message "WATCH FOR TRAINS". Will the driver distinguish this from the standard continuously flashing hazard identification beacon?

Another unresolved problem is the need to activate the advance warning signs before the lights begin flashing at the crossing. Obviously this cannot be done without (possibly unacceptable) modifications to the train detection circuits.

The work by Wimber (1982, ref. 28) is alleged to have led to the introduction in Germany of an amber phase in the signals located at the crossing[3]. This can have no effect on problems which Ruden et al treat and is unlikely to alleviate significantly the decision difficulty identified by Wilde et al.

There is, perhaps, a relatively simple way to alleviate the aforementioned decision difficulty. One could place a vehicle detector 3 seconds upstream of the crossing. If activated, the onset of flashing red could be delayed by 3 seconds. We have not seen this concept mentioned in the literature reviewed.

We are led to conclude that the problem camot be resolved safely within the railroad right of way (because

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1. With, say, 60 vehicles per hour the chance is approximately 0.16-0.25.
2. Using the same data (80 km/h and 60 vehicles per hour, 10-15 seconds comfortable reaction and breaking time), one in four to six drivers faces a dilemma.
3. As this came to our attention belatedly, we could not ascertain the facts.

signals upstream are required) nor is it feasible to do much by "highway action" alone. The two solitudes must recognize the natural jointness of their responsibility when a road and a railway cross, even if history and law tended to make the railway responsible without giving it jurisdiction over the road. Although one can be sympathetic to the reluctance of a railroad to assume responsibility for the operation and maintenance of equipment which is not on its right of way, it is not obvious that a satisfactory arrangement with the highway authority could not be reached.

Should such an arrangement come into being it would be best to think in terms of an activated advance signal, with standby battery power, conveying the `TRAIN WHEN FLASHING - PREPARE TO STOP' message. Seen as an integral part of the crossing protection, the 20 second warning time would apply to the advanced signal with the flashing red at the crossing shortened by, say, 5 seconds. (While 20 seconds is written into regulations, in practice 22 seconds is used anyway. Thus, such a shortening might still be accepted.)

There already are a "number of locations in the country where active advance warning signs are in use. These are at locations where the view of the motorist is restricted...and where there is a steep gradient...used by heavy trucks."[1] There is also an apparent need and willingness to work towards a common solution.[2]

In conclusion, the time seems to be ripe for RTAC or a similar convener to get the railroads, the RTC and the Provinces to hammer out an ad-hoc arrangement in order to engage in a fairly extensive field trial of advance warning signals. At the conclusion of such a trial knowledge would be available to serve as a basis of a more permanent agreement.

5.3 Constant Warning Time Devices, Grade Crossing Predictors and Other Marvels

If there is an element of concensus in this field plagued by controversy, it is about the ill effects of the variability in warning time leading to the poor credibility of signals. Put this together with more than 20 years during which equipment to lick the problem has been

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1. Letter from Mr. R.M. McIntosh, Assistant Director, Standards and Development, Railway Transport Committee, Ottawa, September 12, 1983.
2. Mr. J. O'Hara, Secretary, Railway Transport Committee, writing to Mr. A.D. Cherwenuk, Alberta Transportation expresses the hope that "R.T.A.C. will initiate some action towards this end".

available and you have posed a tantalizing question: Why is this equipment little used[1]?

"In Canada, to date, the two major railways (CN-CP) have made little use of motion sensing systems, and to our knowledge, with the exception of a few early...installations..., they have none operating on a stand-alone basis. (Brownridge and McIntosh, 1983, p. 10, ref. 31)

A motion sensor is a device (placed at the crossing) which sends a low voltage signal through one rail and receives the return signal from the other rail. As the train moves, the impedance of the electrical circuit formed by the rails and the train changes and thus the device can tell whether there is a train and whether it is moving towards or away from the crossing. It does not take much to also continuously predict the time at which the train would arrive at the crossing and to activate flashers (or gates) so as to keep this time constant. This makes motion sensors into grade crossing predictors and constant warning time devices.

Although Brownridge and McIntosh (1983, ref. 31) give the impression that American companies have made extensive use of motion sensors in Canada[2], a U.S. publication also tends to lament their less than wide-spread acceptance[3]. A different source (Railway Progress Institute, 1983, p. 7) indicates to the contrary that "Motion-sensing devices are...used extensively".

In searching for reasons why a railroad might hesitate to use such equipment, cost and unreliability come to mind first.

Indeed, the FHWA (1978, p. 236, ref. 30) claimed that "High costs and high power requirements currently limit the increased installation of these devices. If cost was once of concern, it does not appear to be so now. Brownridge and McIntosh find that the initial cost of a motion sensing

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1. A study sponsored by the U.S. Federal Highway Administration is to be initiated in 1984.
2. "Burlington Northern, the Chessie System and ConRail have all made use of motion sensing systems in Canada, and,...the current policy of B.N. is to use motion sensing equipment at all locations requiring more than a single island track circuit. ...In the U.S.A., Conrail has...a similar system policy..."(p. 11)
3. "Although this equipment has been available for many years and it has demonstrated that it can approach a true CWT (Constant Warning Time) system in operation, its use in the U.S. has been limited to a few railroads..." (Monroe et al., 1981, p. 4, ref. 33)

system and of a conventional 3 track circuit system are about the same, while the motion sensing system may be cheaper and simpler to maintain (p. 22).

While concern about cost may be a red herring, the deeper reasons for non-use of motion sensors may be rooted in concern about their reliability and fail-safeness. This issue is difficult to untangle. Firstly, while the equipment is highly reliable (mean time between failures 2 1/2 - 3 years), the performance of the traditional DC track circuit is difficult to beat (mean time between failures 10 years). In fact, since any motion sensing equipment must be more complex than the track circuit, one cannot expect that the same standard of reliability can be reached. Secondly, low ballast resistance affects grade crossing predictors in a disruptive way. Thirdly, the need to send an additional signal through the rails may interfere with other purposes (eg. block signalling) for which the rails are already used. Brownridge and McIntosh (1983, pp. 12-20, ref. 31) review in detail limited installation tests and reported railway experience. They seem to conclude that, in general, "MS [motion sensing] systems have now been in use for about 20 years, with quite intensive use in the last 5-10 years. The safety of operation during this relatively limited exposure is reported to be better or no worse than with conventional systems" (p. 23). This conclusion is later reflected in their recommendations.

There is, perhaps, legitimate ground for impatience. Why are we still in the "limited exposure" era with 5-10 years of intensive use under our belt and 21 years after the first installation? We were told by professionals in both CN and CP that they worry about the equipment not being fail-safe but that they would be willing to reconsider if there was solid proof. It is not clear how solid the proofs can be in this circumstance. Still, how will one ever be in a position to weigh the solidity of a proof if no grade crossing predictors are put into use because of doubt and prejudice? There seems to be anecdotel evidence of success[1]

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1. "Grade crossing predictors reduce crossing delay and crossing hazard...Along the former CP line, the average gate activation time prior to train arrival was 75 seconds. With the predictors [it]...was reduced to 30 seconds...the frequency of motorists driving around the gates has declined by 50 - 90 percent...predictors accounted for a 17% reduction in crossing delays and a 35% reduction in crossing accidents." C.K. Keck, Mission Impossible. In: Proceedings of the 1982 National Conference on Railroad/Highway Safety.

and rumored horros sotries of failures[2]. Perhaps if we were more intent about finding out just how good or bad grade crossing predictors are, out "exposure" would not now be so "limited".

A deliberate effort in this direction is overdue. It entails a systematic search for empirical evidence accumulated so far, its compilation and analysis. It also entails collection of appropriate information prior to and following installations. Brownridge and Mcintosh (1983, ref. 31) are of course right in concluding that it is essential "to gather statistics on the operational characteristics of the systems" (Recommendations, p. 2). We would tend to broaden the concept of "operational characteristics" to encompass driver behaviour (risk-taking), delay and safety. Just as there is an economic rationale for grade separation projects (Dogson, 1981, ref. 32), so there ought to be one for grade crossing predictors.

Insofar as the slow acceptance of grade crossing predictors is indeed caused by legitimate concern about railroad liability, there is an acute need to summarize the legal situation in Canada. A review akin to that by Glater and Mond (1979, ref. 4), which covered the U.S. situation, should prove useful. It would be conducive to productive discussions in which concensus can be reached on the basis of facts.

A few years ago, a study on new concepts in "constant crossing time" technology was commissioned (Monroe et al., 1981, ref. 33)[1]. With commercial equipment available off the shelf it is natural to raise the question: Why not use this equipment? The reasons the authors give are the relatively low reliability of grade crossing predictors and their occasional incompatibility with other systems which also use the rails as conduits of electric current. One might speculate that this was also a sign of frustration with the slow acceptance of constant warning time devices by the railroads; possibly, it is also a reflection of the

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1. Manufacturers going out of business because of liability claims based on lack of fail-safe operation.
2. Two related studies (Peterson and Boyer, 1977, ref. 35, and Holterman, 1980, ref. 35) also deal, among other things, with elements of a "constant warning time" system that will be discussed later.

thought that to make progress, one has to free grade crossing protection from dependance on the rails and thus, on railroad companies[1].

Monroe et al. (1981, ref. 33) reviewed the promise of seismic, magnetic and accoustic transducers, doppler, guided and two dimensional radars, video sensors, strain gages and proximity switches. They conclude that even for the most promising concepts "a great deal of further testing and development will be required before either of those techniques can be incorporated into a working...system" (p. IX).

We started out by the somewhat provocative question: Why are grade crossing protectors little used? The main reason seems to be the deeply felt conviction that one should not give up even a part of the protection against wrong-side-failures which the track circuit offers. It is important to establish to what extent this conviction is based on a correct perception of exposure to liability and what part is based on vague tradition. More importantly, one has to present solid evidence about the effect of grade crossing predictors on risk-taking, delays, and accidents. Should they prove effective in reducing accidents, perhaps the legal climate would change so that those not using grade crossing predictors would incur high liability risks.

In summary, there is general agreement that the variability in warning times is large and, as a result, the credibility of active grade crossing protection is poor. To improve credibility, some sort of constant warning time device has to be used. Commercially available equipment has the best chance of being accepted. Cost does not seem to be a problem. To speed up the introduction of grade crossing predictors into service, it might be useful to clarify issues of railroad liability, establish the effectiveness of grade crossing predictors and provide the economic rationale for their use.

5.4 Additional Good Ideas

In this section, we aim to present a fistful of the variegated ideas and concepts mentioned in reports which came to our attention. Coverage is far from comprehensive and begins in the early seventies.

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1. J. Hopkins (1974, ref. 36) claims that "...the most important weakness...is the inherent inseparability of track circuits from railroad involvement and responsibility for operation. ...Thus, total public responsibility for crossing protection can be achieved (if desired) only through alternative technology..." (p. 36)

Heathington and Urbanik (1972, ref. 34), imspired by the changeable message signs and the few in-car information and route guidance systems, examine their applicability to highway-grade crossings. The focus is on driver attitudes to such systems, rather than their feasibility and practicality. Feasibility was the focus of an inquiry by Peterson and Boyer (1975, ref. 35). They find costs to be excessive. With recent advances and the increasing availability of on-board intelligence, it would be hardly surprising if these early ideas were soon revisited.

In a seminal paper, Hopkins (1974, ref. 36) made the case for public responsibility for safety at grade crossings and the technological ramifications thereof. In his view, the key for public protection of grade crossings is in a train detection and communication system which does not use the rails and is, therefore, independent of the railroad. He reviews several potential detectors (wheel detectors, inductive loops, magnetometers, beam interruption, pressure, mechanical, solar, radar) and communication systems (radio, microwave telemetry) and relates the results of field tests. In a later report (Hopkins et al., 1975, ref. 37) tests of the microwave concept are described with attention given to train detectors, use of solar power and radar train detection. Two years later (Hopkins, 1977, ref. 29), two versions of the communication link are favoured: microwave telemetry and very-high-frequency radio transmission (which is not limited to line-of-sight operation). The main technical difficulty is with train detection. To gain freedom from track circuits (and thus from railway companies) one would have to retrofit some 50,000 crossings at large cost. The possibilities of using a crossing located radar, a "track radar" and locomotive mounted transmitters are also mentioned. The idea of making the locomotive to trigger the warning at crossings is, at first glance, quite attractive. But, as soon as thought is given to detail, difficulties mount. Thus, for example, even if only a few crossings are to be operated in this manner, all locomotives passing that crossing would have to be suitably equipped. To check for equipment malfunction, one would have to interrogate the crossing equipment and confirm it's functioning in time to stop the train. Neither can one activate all crossings ahead of the train indiscriminately. After covering all such bases, the equipment begins to be complex, cumbersome and costly.

Another contemporaneous brainstorming effort to identify promising innovation is that by Peterson and Boyer (1977, ref. 35). For train detection, they survey direct sensing systems (radar, seismic, infrared, accoustical, etc.) track structure sensing (guided radar, switches, air-gap trans-formers, buried loops, track circuits and non-electrical methods) and train-borne systems (reflective devices, strobe, electromagnets). Three systems are explored in more detail. The idea of using "Optically

Programmed" traffic signals has already been mentioned in Chapter 4. Peterson and Boyer also raise the possibility of improving pavement friction on the approaches. However, most space is devoted to a novel concept of "grade crossing prediction".

A few years later, Nylund and Holterman (1980, ref. 38) again review possible system components, identify two as promising, do limited field testing on one and recommend that it be developed further. The Federal Railroad Administration took yet another stab at "grade crossing prediction" (Monroe et al, 1981, ref. 33). Curiously, the Peterson-Boyer system is not developed further and neither is the Nylund-Holterman system mentioned. After another thorough review of various options, field tests are conducted on two and the conclusion is reached that further testing and development is required.

In this subsection we made an attempt to describe a grab-bag of ideas and concepts which we found in published reports. It is perhaps sufficient to create the impression that this is by no means a field which has been neglected by inventors, consultants and civil servants. One is also left with the impression that in the pile of concepts and ideas there are several which look promising. However, one is also led to conclude that to make progress, it is perhaps insufficient to generate ideas and provide federal funds for concept development and limited field testing.

5.5 Recapitulation

The four subsections of this chapter review an assortment of improvements and innovations aimed at enhancing the safety of grade crossings protected by flashing light type signals.

Conspicuity has been identified as one of the three principal weak spots. In this respect, gradual improvement has been taking place. Of course, more could be done - at cost. It is, however, not known what safety benefits are being obtained by better conspicuity. An effort to find out is perhaps warranted. A departure from standard practice is the use of xenon strobe lights. The shorter and more frequent flashes are an improvement in that one does not need to worry about maintaining precise alignment is an advantage. However, applications are of the add-on nature. This is not in accord with the original intention, which was to replace an inferior system (flashers) by a superior one (strobes). We wonder what caused this change of course.

The fact that the onset of flashing red is sudden, or that in some cases flashers come into view too late, is another weak spot. The remedy is in the form of activated

advance warning signals. The uneasy coexistence of rail and highway authorities causes practical solutions to be halfway measures.

We conclude that solutions which are either "highway alone" or "railway alone" are likely to be compromises which seriously degrade effectiveness. Should it be possible for the highway and railway authorities to come to an arrangement it appears entirely feasible to devise a good advance warning system. An extensive field trial should lead to insight about effectiveness, costs and other matters which need clarification before a permanent program is put into effect.

The third and possibly most serious problem with the standard flashing lights type protection is the variability of warning time resulting in lack of "credibility". The cure for this problem is in the wide-scale installation of "constant warning time" devices. The two major railways in Canada have not made substantial use of such devices in spite of their commercial availability for over two decades. The often stated reason is concern that their use would degrade the customary standard of fail-safeness. We find this argument to be convincing only if protection against liability is the only game in town. One ought to find out to what extent the installation of constant crossing time devices saves accidents, reduces delay and encourages signal obedience.

One should also find out what are the factual ingredients of the legal situation in Canada with respect to railroad liability. Such intelligence is needed in order to engage in constructive dialogue. Should elements of a concensus emerge one could also begin work on providing an economic rationale for the installation of grade crossing predictors.

In reviewing the multitude of good ideas conceived and researched over the years one must be moved by two contrary emotions: admiration of inventiveness and frustration by lack of progress. If implementation is what counts, it is entirely insufficient to only generate ideas, do field testing and hope to find gold. Perhaps it is necessary to secure at the outset the cooperation of the three main constituencies: the government, as the proxy of the public, the railroad companies and the manufacturers of equipment. This requires a Japanese-style attitude to bringing into existence successful new technology. The going-it-alone attitude which motivated much of the work so far, did not seem to make an impression on the industry and its practice.

6. A SUMMARY (FOR EXECUTIVES AND COMMONERS)

Our purpose was to diagnose what ails the flashing light type warning device, to survey what possible remedies incline the mind and to indicate what appear to be profitable directions to pursue. For correspondence with the five previous chapters the narrative there is divided into five numbered sections. Specific recommendations and conclusions are in boldface.

1. The antecedent of the present day flashers is a red lantern swung by a watchman. This immediately causes prejudice: why do we still use a device derived from and possibly best suited for horse-and-buggy traffic? The track circuit which serves to detect trains is not a modern idea either; it dates back to 1887. When a train shorts a track circuit or when anything goes wrong, lights begin to flash. This "fail-safe" attribute of the simple track circuit introduced in the nineteenth century is the core of today's difficulties.

The system is not fail-safe in the sense that no accidents occur. For all we know, the false alarms and long warning times which come with being "fail-safe" may actually foster behaviour which causes some accidents. The system is only fail-safe in the sense that the railway is almost always in a position to say: "it's your fault, you should have obeyed the lights". This serves to point out the distinction between being "safe" and being "fail-safe". It would be nice if crossings could be made safe and the systems protecting them fail-safe. Alas, this is difficult to do. Pushing down the rate at which "wrong side" failures occur will often cause the rate of false alarms to rise. Also, it is difficult to beat simplicity. Complex systems have many ways in which to fail.

One design decision leads to another. If the system is to be "fail-safe" it has to operate on standby batteries in case of network power outage. If so, the lights used can not consume much power. This in turn makes it necessary to focus the light into narrow beams and to maintain the signals in precise allignment. The same need to use batteries is also said to limit the ability to display the familiar green-amber-red as traffic signals do. Perhaps the reason for this is different; it may be the wish not to tell the motorist that he has the right of way by displaying green. Is this double protection against liability a correct response to an adverse legal situation?

This question deserves research attention. Evidence from the U.S. indicates that the use of exposure to liability as an argument against technological innovation has no basis in legal case histories. Our situation may be entirely different. In any case, real and perceived risk of

liability seems to be the fulcrum on which everything hinges. The sooner fact is separated from folklore the better. Thus, a study of the relevant aspects of the railroad's legal liability for grade crossing accidents should be undertaken. It should entail a review and analysis of court decisions and should attempt to give advice about the liability aspect of such issues as rail-highway cooperation in advance warning signals (5.8 below), use of grade crossing predictors (5.6 below), etc.

2. There are, in Canada, some 6000 crossings with flashing light type protection. CN alone puts in some 120 new installations per year. A new installation costs close to $60,000. Thus, the size of the program in economic terms seems large enough to justify worrying about possible deficiencies of the flashing light type protection and to investigate options for their rectification. However, remembering that at these 6000 crossings, we record only some 350-400 collisions per year, puts the problem in a different light. Could public money used here[1] be better used elsewhere?

To answer, one has to know how effective flashers are in reducing accidents. On this matter, there is a curious paradox. Before-and-after studies all point to a 60% - 70% reduction in accidents when protection is increased from crossbucks to flashers. There is a good chance that they are all wrong. The comparison of crossbucks and flashers working under similar conditions shows that effectiveness is perhaps in the 0% - 30% range. Thus, it just may be that we are investing in a near-useless device. Therefore, before embarking upon attempts to improve some aspects of the flashing light and bells protection, it makes sense to settle the effectiveness question. The techniques to do so are now available.

3. The various shortcomings of the flashing light type protection are best described under three headings: deficiencies in conspicuity, sudden onset and lack of credibility.

a. Failure to recognize a crossing signal plays a major role in perhaps 20% - 30% of vehicle-train collisions, which themselves are only about 1/3 of all crossing accidents[2]. It is not known what reduction in these target accidents can be expected if conspicuity is improved. We only know that improvements could be made.

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1. The Canadian Transport Commission pays 80% of the initial costs, the railroad 7.5%. The rest is paid by the appropriate road authority.
2. These estimates are imprecise as they are based on a small accident data-set.

b. There are two circumstances in which the driver is suddenly faced with the flashing red lights. First, if he happens to be close to the crossing when the signal is activated. Second, if due to road geometry, obstructions or signal misallignment, the lights become visible when it is too late to stop. It is not easy to describe the seriousness of this deficiency in terms of accidents. It is also difficult to observe related conflicts or irregular maneuvers in the field. This is perhaps why the "sudden onset" deficiency has been recognized more at the level of the intellect than on the basis of factual diagnosis.

c. In contrast, evidence of "credibility" problems is ubiquitous. It is there in terms of the many drivers (about 16%) who recognize the flashing signals and still cross. It is also there in the form of collisions involving drivers who did see the signals, could stop safely but did not. Putting the blame on warning time variability may be a partial cop-out. It appears that in about 1/2 of all vehicle-train collisions, the driver not only saw the signals and disregarded them, but he also saw the approaching train. What can be more credible than a speeding locomotive? If the large variability in warning time induces people to take grave risks, one set of countermeasures is indicated. If, however, the inability to judge distance, speed or time is the main culprit, or if possibly suicide or risk related arousal play a dominant role, a different set of measures must be contemplated.

4. Ordinary traffic signals are well visible, contain an "amber" phase to cushion the onset of red and are relatively well respected by the motorist. Besides, driving through red at a traffic signal is an offence, which makes enforcement possible and prosecution easy. Why not use traffic signals at rail crossings?

Experts differ in their opinions. The argument can be separated into five strands.

a. Would use of traffic signals at grade crossings make for substantially less risk-taking and would such use have an adverse effect on the obedience of trafic signals at intersections? Taking our clues from a similar use of stop signs we conclude that unless the variability of warning time is drastically altered, it is unlikely that there will be a longterm "transfer of respect" from the intersection to the crossing. Nor would there be a measurable transfer of disrespect in the opposite direction. The net effect might simply be an increase in the number of violations of the Highway Traffic Act at grade crossings.

However, traffic engineers worry about a creeping change in the observance of traffic control devices due to unwarranted proliferation. While we know of no solid evidence, this concern should not be taken lightly.

b. Would the use of traffic signals make for less "traffic turbulence" at crossings? The answer is: most likely yes. However, this cures only a part of the driver-too-close-when-signal-comes-on problem. It does not affect the signal-comes-into-view-belatedly problem which seems to be receiving most of the engineering attention. One can affect both problems simultaneously and help the driver better by warning him in advance of the crossing that when he gets there he will find the red lights flashing.

c. Would traffic signals be more conspicuous than standard flashers? The answer is again yes. There are technical problems having to do with standby power which need to be resolved first. If these can be resolved then one can make crossing signals more conspicuous in many ways - not only by using traffic signals.

d. Traffic signals require network power. When power fails the regular flashers have to provide backup. Thus the cost of traffic signals will be on top of the cost of the regular installation.

e. To display green by a traffic signal at a crossing would be a radical departure from present railroad practice and philosophy. It would raise difficult problems of liability jurisdiction, fail-safe operation, cost sharing and cooperation which make the acceptability of such a practice unlikely.

We conclude that, on balance, there is little to commend the widespread use of traffic signals at grade crossings. It seems best to wait for results of ongoing research in the U.S.

5. Deficient conspicuity, sudden onset and lack of credibility were the three major shortcomings noted. Remedies to these are discussed below in paragraphs a, b and c. In paragraph d we deal with ideas and innovations which do not fit neatly elsewhere.

a. Over the years the conspicuity of flashers has been gradually improving through the use of higher intensity lamps, a more transparent shade of red, more efficient optical systems, etc. Concurrently, considerable work has been done on the use of xenon strobe lights. For reasons which are not entirely clear, strobe lights are being thought of as supplementing rather than replacing incandescent lights. It also remains unclear what effect both the gradual and the radical improvements in conspicuity had, or would have, on accidents. In the absence of such knowledge, it is rather difficult to know whether money is being well spent and whether a retrofitting program is justified. **Thus, before anything else, one has to come to some defensible view on**

the accident reduction which can be attributed to better signal conspicuity. On the future of xenon strobe lights, it may be sensible to take a wait-and-see position.

b. We recognized earlier in section 3.b the two circumstances in which a driver is suddenly faced with flashing red lights. The one occurs at all crossings if he is too close to the tracks when the lights come on. The other occurs only at places at which there are sight distance limitations on the road. Activated advance warning signals to deal with the latter situation were developed and tested. Failure to agree on a joint railway-highway approach left some problems unresolved and led to an inferior solution. There is current interest in Canada in this problem and perhaps also willingness to work towards a common solution. We conclude that the time is ripe for an initiative, perhaps by RTAC, to secure cooperation and to work towards a field trial of advance warning signals.

c. There is little doubt that the variability in warning time is a problem. A variety of commercially available motion sensing equipment has been available for a very long time. In Canada its use by CN and CP is negligible. The reason for lack of use is not cost but concern about abandoning the security of fail-safeness. It is astonishing that 21 years after the first installation of a grade crossing predictor the major railroads should still be "unsure" and be permitted to stay so. A deliberate effort to get out of this blissful ignorance seems long overdue. It entails the collation and interpretation of empirical evidence accumulated in North America. This is to be followed up by a vigorous demonstration program of trial installations. At each installation, data should be recorded on reliability and other operational characteristics. In addition, before-and-after data on delay, driver behaviour, near misses and accidents should be collected. When sufficient empirical evidence is accumulated, thought should be given to a formal economic rationale to serve as a basis to an orderly program. The associated legal issues should have been covered in the study already described in section 1 of this chapter.

In recent years, considerable effort has gone into research on developing more reliable "constant warning time" technology. Our understanding is that, while promise has been shown, it is not possible to tell when such a novel device might be marketed. It is therefore sensible to stick with what is commercially available and to demonstrate whether the use of grade crossing predictors is in the best interest of the railroad and the motorist.

d. In addition to the various ideas and concepts already mentioned, there is a large body of literature which describes an assortment of exciting and elegant innovations. The impression is that the field teems with inventors, researchers,

consultants and civil servants. It is not lack of attention which makes for slow progress. Much of the research effort seems to have been inspired by a desire to provide protection at the crossing without having to use the tracks and thereby diminishing the required degree of cooperation with the railway. Thus far, the going-it-alone effort has few results to show. Perhaps it is naive to hope that it is possible to secure the cooperation of the railways, the equipment manufacturers and the government in a Japanese-style attempt to bring into use novel technology. Nevertheless, this seems to be the sensible way to go in this case.

POSTSCRIPT

In closing, it only remains to thank the many persons whose patience we tried by asking questions as neophytes would ask. We hope to have read the printed work correctly, interpreted oral comments without bias and presented a review not lacking in balance. The opinions expressed are, of course, our own. It was our task here to bring out contrast and we therefore apologize for opinions which may have been expressed with too much emphasis.

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